The High Redshift ($z > 3$) AGN Population In The 4 Ms Chandra Deep Field South

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Outline

High-redshift AGN issues

- physical properties (obscuration)
- evolution (space density, obscured AGN fraction)
- Observables: spectral properties, number counts, etc.
- Need for large (high-redshift) samples

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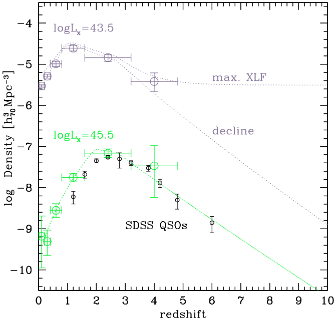
  (X-ray) surveys

  COSMOS (Brusa et al. 2009, Civano et al. 2011)

  4 Ms CDF-S (Fiore et al. 2012, Lehmer et al. 2012)



(Gilli et al., 2011)

Selection criteria

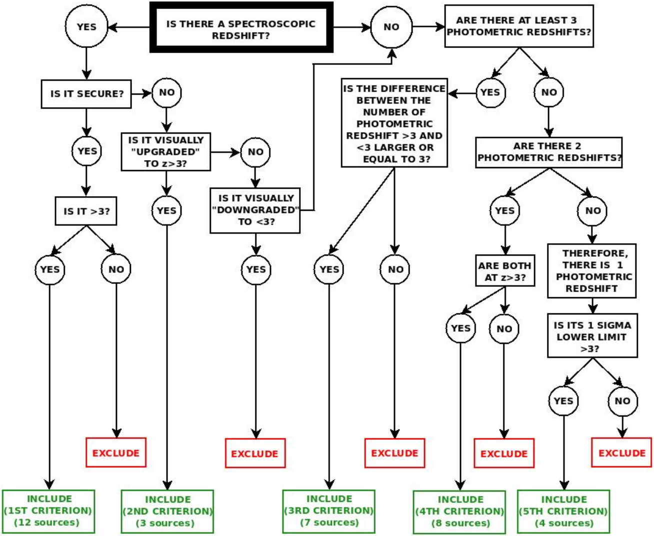
65 sources have zadopt > 3 in Xue et al. (2011)

96 sources have $z > 3$ in at least 1 of the considered catalogues

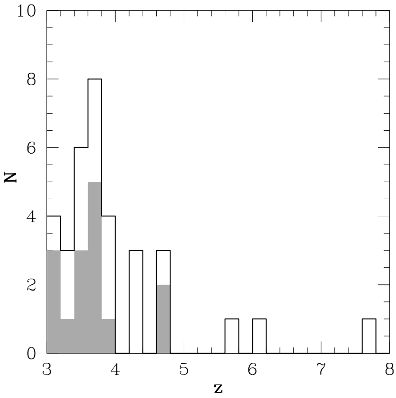
1. "Secure" spectroscopic $z > 3$ **(12 sources)**
2. "Insecure" spectroscopic $z > 3$, upgraded to "secure" through visual inspection **(3 sources)**
3. When more than 2 phot-z are available, $N_{z_{phot}>3} - N_{z_{phot}<3} \geq 3$ **(7 sources)**
4. When only 2 phot-z are available, both are at $z > 3$ **(8 sources)**
5. When only one phot-z is available, its 1σ lower limit is at $z > 3$ **(4 sources)**

TOTAL: 34 SOURCES (15 with spec-z)

Selection criteria

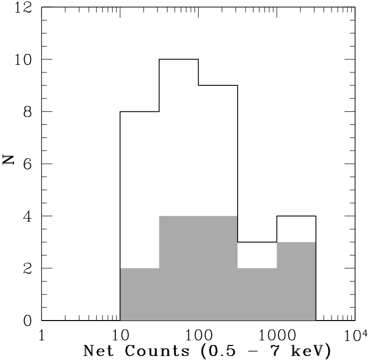


Redshift distribution

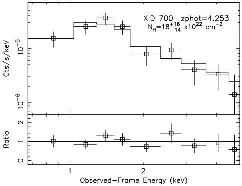


Grey shaded histogram: 15 sources with spec-z
Median redshift: $z = 3.7$

$0.5 - 7$ keV Net-counts distribution



Median net counts: 80



Low statistics

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simple spectral model

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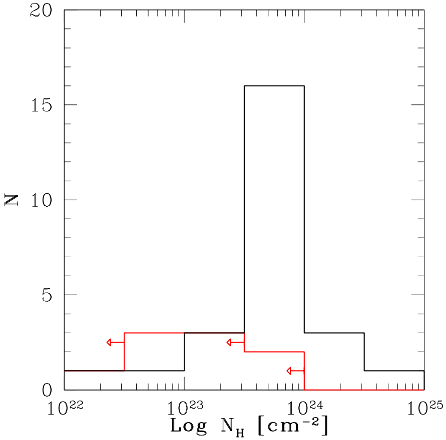
Absorbed power-law ($\Gamma = 1.8$)

↓

Focus on the column density

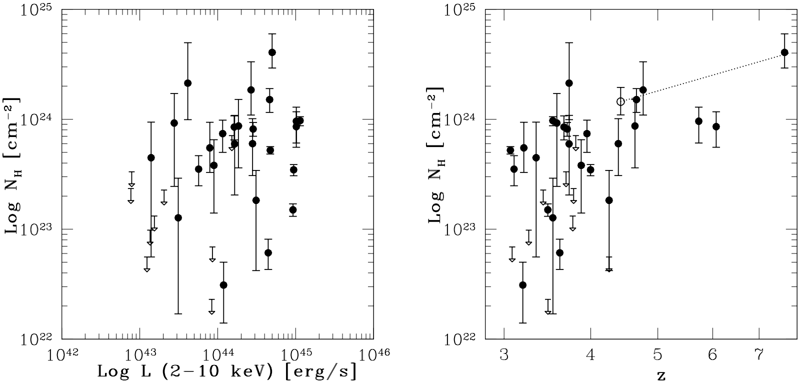
N_H distribution



$\sim$ 68% strongly obscured ($N_H > 10^{23}\,\mathrm{cm}^{-2}$) sources

Possible bias due to low statistics and high-z (overestimate of the column density)

N_H, z and L_X



Median $L_{2-10\ \mathrm{keV}} = 1.52 \times 10^{44}\ \mathrm{erg\ s^{-1}}$

Correction factors for the N_H distribution

Problem: possible N_H overestimation due to low statistics and high-z

$\downarrow$

How many times a X-ray spectrum intrinsically absorbed by a column density N_{H_j} is best-fitted by a different column density N_{H_i}?

$\downarrow$

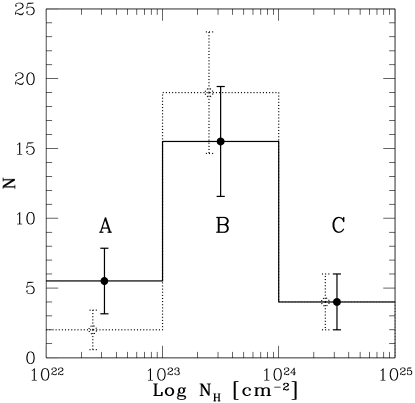
Spectral simulations!

$\downarrow$

Correction factors P_{ij}
(probability to derive N_{H_i} given an intrinsic N_{H_j})

Corrected N_H distribution

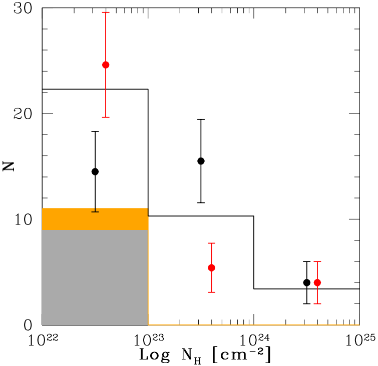
- $N_A = 2 \rightarrow X_A = 5.5$
- $N_B = 19 \rightarrow X_B = 15.5$
- $N_C = 4 \rightarrow X_C = 4$



Dashed line: observed distribution

Solid line: corrected (intrinsic) distribution

Corrected N_H distribution: comparison with model



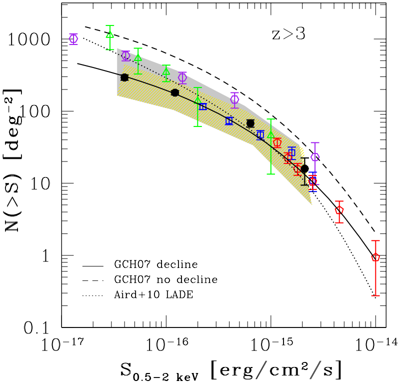
Black points: intrinsic N_H distribution ($\Gamma = 1.8$)

Red points: intrinsic N_H distribution ($\Gamma = 1.6$)

Shaded areas: upper limits

Histogram: Gilli et al. (2007) XRB synthesis model with high-z decline (no evolution with redshift at the 2σ c.l.)

$z > 3$ LogN-LogS

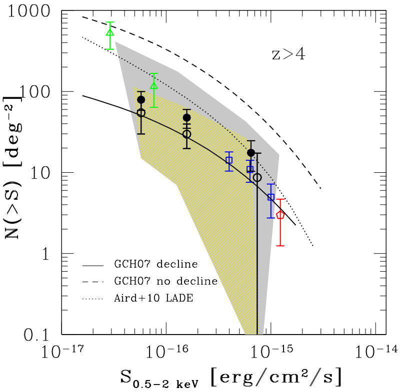


Black: this work
Brusa et al. (2009)
Civano et al. (2011)
Fiore et al. (2012)
Lehmer et al. (2012)

Yellow shaded area: relaxing/tightening the selection criteria

Grey shaded area: adding 39 sources without redshift in any catalogue

$z > 4$ LogN-LogS



Black: this work
Brusa et al. (2009)
Civano et al. (2011)
Fiore et al. (2012)
Empty circles: excluding the 3 sources at $z > 5$

Yellow shaded area: relaxing/tightening the selection criteria

Grey shaded area: adding 39 sources without redshift in any catalogue

Conclusions

- 34 X-ray selected AGN at $z > 3$ (15 with spec-z) in the 4 Ms CDF-S
- Large fraction ($\sim 68\%$) of obscured sources (but possible biases). Typical luminosity $L_{2-10 \text{ keV}} \approx 10^{44} \text{ erg s}^{-1}$
- Corrected N_H distribution consistent (within 2σ) with no evolution of obscuration with redshift
- LogN-LogS in agreement with a decline in the high-z AGN space density

Catalogues

740 X-ray sources in the 4 Ms CDF-S main catalogue (Xue et al. 2011)

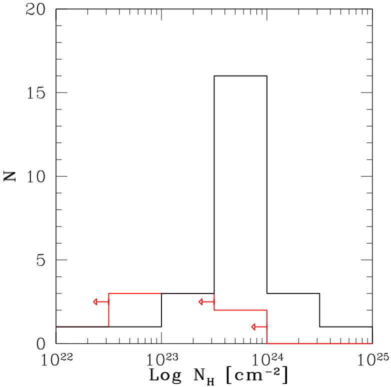
Spectroscopic redshifts:
Szokoly et al. (2004); Vanzella et al. (2008); Popesso et al. (2009); Wuyts et al. (2009); Silverman et al. (2010); Vanzella et al. (2010); Vanzella et al. (private communication).

Photometric redshifts:
Luo et al. (2010), Cardamone et al. (2010); Rafferty et al. (2011); Santini et al. (2009); Wuyts et al. (2008); Taylor et al. (2009); Dahlen et al. (2010).

Correction factors for the N_H distribution

Sample divided into 3 N_H range (only sources with constrained best-fitting N_H):

- **A:**
  $log(\frac{N_H}{\mathrm{cm}^{-2}}) < 23$
  (2 sources)
- **B:**
  $23 < logN_H < 24$
  (19 sources)
- **C:**
  $logN_H > 24$
  (4 sources)



Correction factors for the N_H distribution

$$N_A = \sum_{j=A}^{C} X_j P_{Aj}$$

$$N_B = \sum_{j=A}^{C} X_j P_{Bj}$$

$$N_C = \sum_{j=A}^{C} X_j P_{Cj}$$

where $\mathbf{N_i}$ is the number of sources with (observed) best-fitting N_H in the i-th bin; $\mathbf{X_j}$ is the number of sources with intrinsic N_H in the j-th bin; $\mathbf{P_{ij}}$ is the probability to derive a best-fitting N_H in the i-th bin, given an intrinsic N_H in the j-th bin.

$i, j =$ A, B, C

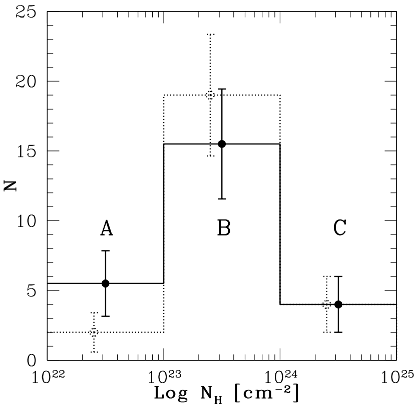
Correction factors for the N_H distribution: (basic) procedure

For $i, j =$ A, B, C:

1. 1000 simulations of a X-ray spectrum with $\Gamma = 1.8$, N_H in the j-th bin, 100 net counts at $z = 4$ ($\approx$ median values of the sample)
2. Fit of the 1000 simulated spectra to derive the best-fitting N_H
3. Counting how many times the best-fitting N_H lies in the i-th bin $\rightarrow P_{ij}$

Corrected N_H distribution

$\Gamma = 1.8$			
P_{ij}	j=A	j=B	j=C
i=A	0.361	0.0	0.0
i=B	0.639	1.0	0.0
i=C	0.0	0.0	1.0



- $N_A = 2 \rightarrow X_A = 5.5$
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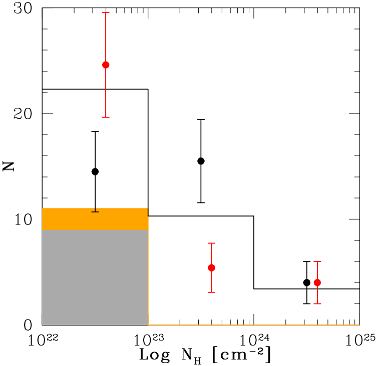
Dashed line: observed distribution

Solid line: corrected (intrinsic) distribution

Corrected N_H distribution: comparison with model



Black points: intrinsic N_H distribution ($\Gamma = 1.8$)

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$\Gamma = 1.6$			
P_{ij}	j=A	j=B	j=C
i=A	0.147	0.0	0.0
i=B	0.853	1.0	0.0
i=C	0.0	0.0	1.0

Shaded areas: upper limits

Histogram: Gilli et al. (2007) XRB synthesis model with high-z decline (no evolution with redshift at the 2σ c.l.)